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INVESTIGATION TO RECOVER Ni-Co-Fe-Cr FROM ORE SAMPLES SUBMITTED BY BORDER RESOURCES

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INVESTIGATION TO RECOVER Ni-Co-Fe-Cr FROM ORE SAMPLES SUBMITTED BY BORDER RESOURCES

by

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ABSTRACT

Samples of serpentine ore collected from a deposit located in British Columbia were investigated for the recovery of Ni, Co, Fe and Cr.

The samples exhibited low content in the metals of interest: 0.2% Ni; 0.012% Co; 6.24% Fe and 0.27% Cr.

The recovery of Ni-Co by flotation was difficult to achieve due to the intimate association of the valuable minerals and to their slow response to flotation. Various levels of Ni and Co concentration were obtained by successive flotation cleanings. At 6% Ni and 0.3% Co the recovery in open circuit was 30% for both metals.

The separation of Fe and Cr minerals by magnetic concentration was not possible. Also the upgrading of the Ni flotation tailing or the original ore by magnetic separation to saleable iron concentrate could not be achieved. Concentrates of only 40% Fe and 1.4% Cr were obtained for a recovery of 33% for Fe and 30% for Cr.

Recommendations are made to continue the exploration of the deposit searching for zones of better mineralization. Investigation to upgrade the ore should resume when ore of better quality is found.

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INTRODUCTION

Following the request of Border Resources Ltd. of Vancouver, B.C. an investigation was initiated to study the possibility of recovering nickel-bearing sulphides and other valuable minerals of Co, Fe and Cr from a serpentine ore deposit located in B.C.

A company providing consulting services in mineral processing, A-Min-Tech Research Ltd. also of Vancouver, B.C., acted as a technical advisor for Border Resources Ltd.

Previous testwork performed by A-Min-Tech Research on some samples originating from Border Resources deposit was focused on Ni-Co flotation and indicated that the upgrading of the ore to saleable concentrate at a good metal recoveries was difficult to achieve.

CANMET carried out a reduced test program attempting to improve the Ni-Co flotation results obtained by A-Min-Tech and to achieve concentration of the iron and chromium minerals by magnetic separation. Also, the preconcentration of all valuable minerals by gravity separation method was tried.

The best Ni-Co flotation concentrates were assayed for precious metals to determine their possible concentration in the final products.

Finally, microscopic examination was performed in the Mineralogical Laboratory to investigate the nature of Ni-Co mineralization and the association of the minerals. The results of this work will be reported under a separate cover.

The progress and results of the testwork were examined and disscused in frequent meetings and telephone conversations with Dr. H. von Hahn of A-Min-Tech Research Ltd.

OBJECTIVES OF THE TESTWORK

The object of the testwork was to investigate the possibility of obtaining, by mineral dressing methods, from Border Resources serpentine samples the following products:

- Ni-Co concentrate of minimum 6% Ni
- Fe concentrate
- Cr concentrate

HEAD ASSAY OF ORE SAMPLES

Two samples were provided by Border Resources for the testwork. They were identified as:

- Site #9 and
- Site #11

Both were serpentine type ore samples and site #11 contained more fibrous minerals than site #9.

The samples were crushed and prepared for chemical assay and testwork.

All the chemical assays were performed by Bondar and Clegg Company in Ottawa, with the exception of some determinations aimed to isolate the sulphide Ni from total Ni, that were done in CANMET Chemical Laboratories.

The head assay of the samples is presented in Table 1.

Table 1 - Head assay

Element	Site #9 %	Site #11 %	Element	Site #9		Site #11	
				oz/ton	g/t	oz/ton	g/t
Ni	0.21	0.20	Au	< 0.005	< 0.17	< 0.005	< 0.17
Co	0.012	0.014	Ag	0.02	0.69	< 0.02	< 0.69
Cu	0.003	0.004	Pt	< 0.002	< 0.07	< 0.002	< 0.07
Fe	6.24	5.30					
Cr	0.27	0.25					
S	0.060	0.047					

Table 2 gives the results of CANMET determinations to isolate the sulphide from total nickel. The Ni soluble in ascorbic acid - hydrogen peroxide mixture was reported as sulphide Ni.

Table 2 - Ni assay (CANMET)

Sample	Assay, Ni %		% Dist. Ni Sulph
	Total	Sulphide	
Site #9	0.22	0.17	77.3
Site #11	0.21	0.12	57.1

According to these data, the nickel tied up in a sulphide form is 77.3% and 57.1% of the total nickel for sites #9 and #11 respectively.

TESTWORK

The following investigations were conducted:

- Grinding test to determine the conditions for grinding the ore to various sizes
- Gravity concentration tests to recover the heavy minerals
- Flotation tests to recover the Ni and Co
- Magnetic concentration tests to recovery the Fe and Cr

Most of the testwork was carried out with site #9 sample and only few experiments were performed with site #11 which was a material more difficult to process.

GRINDING TESTS

Several tests were carried out to determine the conditions under which the ore samples could be ground to -150 µm (100 mesh); -74 µm (200 mesh); -37 µm (400 mesh); -30 µm (500 mesh).

The equipment used to grind the ore was a laboratory steel mill having a grinding balls load of 17,656 g.

The grinding conditions for various sizes are given in Table 3.

Table 3 - Grinding conditions

Site	Grind		Charge g	Slurry % solids	Grind time min.	Ground ore % passing
	µm	Mesh				
9	150	-100	2000	50	30	72.9% - 74 µm
	74	-200	2000	60	57	95.4% - 74 µm
	37	-400	2000	60	150	98.0% - 37 µm
	30	-500	2000	60	300	98.6% - 30 µm
11	150	-100	2000	50	25	71.8% - 74 µm
	74	-200	2000	50	58	96.1% - 74 µm

Two tests were carried out using stage grinding for a total grinding time of 342 minutes for 3-stage grinding and 147 minutes for 2-stage grinding with desliming between stages.

GRAVITY CONCENTRATION

Several tests were carried out to examine the possibility of preconcentrating all heavy minerals (Ni, Co, Fe, Cr) by a gravity separation method.

Samples ground to -150 and -74 microns from sites 9 and 11 were processed on a laboratory Wifley table.

The results of the table tests showed no trend of a significant concentration in any of the table products. This method of investigation was not considered appropriate for this type of ore and it was abandoned.

FLOTATION

The recovery of Ni and Co in a collective concentrate was tried by flotation.

The flotation tests were conducted in the following sequence:

Tests to Reproduce the A-Min-Tech Conditions

Three tests were carried out, two with site #11 and one with site #9, to reproduce the conditions and results previously obtained with this

material by A-Min-Tech. Under similar grinding conditions and reagent regime the results obtained by us with sites #9 and #11 were inferior to those previously reported by A-Min-Tech.

A comparison between the metallurgical data obtained by CANMET and those reported by A-Min-Tech is presented in Table 4.

Table 4 - Metallurgical results, CANMET vs A-Min-Tech

Research unit	Test no	Site no	Products	% Weight	Assay %		% Dist.	
					Ni	Co	Ni	Co
CANMET	1	11	Conc 1-3	8.8	0.45	0.025	19.5	19.4
			Tails	91.2	0.18	0.010	80.5	80.6
			Head	100.0	0.20	0.011	100.0	100.0
A-Min-Tech	PRF-16	11	Conc 1-4	7.3	1.13	0.055	40.7	42.0
			Tails	92.7	0.13	0.006	59.3	58.0
			Head	100.0	0.20	0.010	100.0	100.0
CANMET	2	9	Conc 1-3	7.2	0.83	0.042	28.6	34.9
			Tails	92.8	0.16	0.006	71.4	65.1
			Head	100.0	0.21	0.009	100.0	100.0
A-Min-Tech	BRF-8	4	Conc 1-3	4.8	2.29	0.133	53.7	52.8
			Tails	95.2	0.10	0.006	46.3	47.2
			Head	100.0	0.21	0.012	100.0	100.0

The ore identified as site #4 was similar to that of site #9.

No explanation could be found as to why the A-Min-Tech results were not reproduced by CANMET, except probably that the characteristics of the material were different.

Rougher Flotation Tests

Several flotation tests were then carried out to adjust and improve the Ni-Co recovery in the rougher stage. Site #9 ore was used for these tests since this material appeared to be less difficult to upgrade than site #11.

Most of the tests were performed under -74µm (200 mesh) grinding conditions and the best conditions were then applied to -37 µm (400 mesh) and -30 µm (500 mesh) ground ore.

In an attempt to increase the metals recovery two tests were performed with stage-grinding, flotation being carried out between grinding stages. In one of those tests (Test 19a-b-c) the ore was first ground to -74 µm and the Ni-Co was floated. Then the tailing was again ground after which another series of Ni-Co concentrates were collected. Finally the second flotation tailings were ground for the third time followed by a third series of Ni-Co flotation. In the other test (Test 22a-b) the ore was ground to -74 µm and Ni-Co was floated. Then the rougher tails were deslimed twice and the deslimed material was again ground after which Ni-Co concentrates were again collected.

The metallurgical data and conditions of the most significant tests of the rougher flotation are summarized in Table 5. The flotation time for collecting each concentrate was 5 minutes for all tests except test #21 and 22a-b, where the time was 10 minutes.

In one test the flotation products were assayed for total Ni, and total Ni and sulphide Ni, to determine the efficiency of the flotation process as regards the nickel extraction. The results of this test are presented in Table 6.

Table 5 - Summary of rougher flotation conditions and results

Test no. (Site)	Grind	pH	Reagents Types	Reagents g/t	Products	% Wt	Assay % Ni	Assay % Co	% Dist Ni	% Dist Co
			C.M.C.*	1500	Conc 1-3	2.3	1.68		18.0	
	-150 µm		Aero-208	100	Tails	97.7	0.17		81.1	
32	(100 mesh)	9.7	Aero-3477	55	Head	100.0	0.20		100.0	
(9)			Xanthate-350	55						
			Dow Froth-250	36						
	-74 µm		Same as test		Conc 1-3	5.0	1.34		33.6	
6	(200 mesh)	9.8	32		Tails	95.0	0.14		66.4	
(9)					Head	100.0	0.20		100.0	
	-37 µm		C.M.C.	2500	Conc 1-3	7.8	1.03		38.4	
16-A	(400 mesh)	9.2	Collectors as	210	Tails	92.2	0.14		61.6	
(9)			above		Head	100.0	0.21		100.0	
			DF-250	9						
	-30 µm		C.M.C.	3750	Conc 1-3	15.6	0.63		47.4	
28	(500 mesh)	9.6	Collectors as	210	Tails	84.4	0.13		52.6	
(9)			above		Head	100.0	0.21		100.0	
			DF-250	18						
	3-stage		C.M.C.	4500	Conc 1-9	32.0	0.44	0.021	65.4	71.3
19	grind	9.6-	Aero-208	300	Tails	68.0	0.11	0.004	34.6	28.7
a-b-c	-37 µm	9.8	Aero-3477	165	Head	100.0	0.22	0.009	100.0	100.0
(9)	(400 mesh)		Xanthate-350	165						
			DF-250	81						
	2-stage		C.M.C.	3000	Conc 1-6	26.0	0.48	0.025	60.3	68.8
22	grind	9.7-	Aero-208	200	Slimes	2.6	0.11	0.006	1.5	2.2
a-b	-37 µm	9.8	Aero-3477	110	Tails	71.4	0.11	0.004	38.2	31.2
(9)	(400 mesh)		Xanthate-350	110	Head	100.0	0.21	0.009	100.0	100.0
			DF-250	63						
	-37 µm		Same as test		Conc 1-3	12.9	0.75		48.0	
21	(400 mesh)	9.7	16-A, except		Tails	87.1	0.12		52.0	
(9)			longer flot. time		Head	100.0	0.20		100.0	
	-37 µm		Same as test		Conc 1-3	13.5	0.56		36.6	
18	(400 mesh)	9.0	16-A, except		Tails	86.5	0.15		63.4	
(11)			DF-250	81	Head	100.0	0.21		100.0	

*Carboxymethylcellulose

Table 6 - Flotation results based on sulphides assay

Product	% Weight	Assay %			% Dist.		
		Ni total	Ni Sulphide	Ni non-sulph.	Ni total	Ni Sulphide	Ni non-sulph.
Conc -1	2.0	1.98	1.87	0.11	18.1	23.7	3.6
Conc -2	1.8	0.96	0.89	0.07	7.9	10.1	2.1
Conc -3	2.0	0.57	0.51	0.06	5.2	6.5	2.0
Conc 1-3	5.8	1.18	1.10	0.08	31.2	40.3	7.7
Tails	94.2	0.16	0.10	0.06	68.8	59.7	92.3
Head	100.0	0.22	0.16	0.06	100.0	100.0	100.0

Based on the results presented in Table 5 and 6 the following comments can be made:

(a) The nickel recovery increased with the fineness of grind but even when the size of the particles was 98.6% -30 microns the nickel extraction did not exceed 47.4%.

(b) By using longer flotation time or stage grinding - flotation, the nickel extraction rose in some tests to 65.4% but the concentrate was impurified with a large quantity of gangue which drastically reduced the grade of the Ni product.

(c) The required amount of C.M.C. to depress the gangue minerals increased with the fineness of grind. This reagent seemed to be a very efficient depressant for the serpentine gangue, however the required large consumption (1.5-4.5 kg/t) and its high cost ($2.03/kg) might be very expensive in industrial application.

(d) The recovery of sulphide nickel was better than that of total nickel but probably because of the initimate association of the pentlandite with the gangue minerals, even the extraction of sulphide nickel was not satisfactory.

(e) The results obtained with site #11 ore were inferior to those resulting by processing site #9 under the same conditions.

Cleaner Flotation Tests

Several flotation tests were carried out to determine the possibility of upgrading the nickel product by re-floating the rougher concentrate.

Since the Ni concentration in the original ore was quite low it was necessary to process large amounts of material in the rougher stage to obtain enough quantity of rougher concentrate for the next cleaning stages. The collecting of the rougher concentrate took several days and the concentrate saved during this period in preparation for cleaning might have suffered some aging effects which could, to a certain extent, have affected the results of the flotation in the cleaning stages.

A summary of the conditions and results of the flotation cleaning tests is shown in Table 7.

Table 7 - Summary of cleaning flotation results

Test no.	Grind	Reagent (cleaning) Type	g/t*	Product	% weight	Assay % Ni	% Dist. Ni
29	-74 µm (-200 mesh)	CMC (1st Cl. Fl.)	100	3rd Cl. Conc	0.60	9.02	26.0
		(2nd Cl. Fl.)	26	2nd Cl. Conc	1.00	6.35	30.5
		(3rd Cl. Fl.)	3	1st Cl. Conc	2.50	2.73	32.8
				Rougher Conc	11.80	0.72	40.8
		Xanthate 350	2.8	1st Cl. Tails	9.30	0.18	8.0
				Rougher Tails	88.20	0.14	59.2
30	-74 µm (-200 mesh)	CMC (2nd Cl. Fl.)	10	4th Cl. Conc	0.24	12.30	14.4
		(3rd Cl. Fl.)	2	3rd Cl. Conc	0.29	11.72	16.6
				2nd Cl. Conc	0.50	8.02	19.6
		Xanthate 350	0.4	1st Cl. Conc	0.99	4.61	22.3
				Rougher Conc	4.42	1.39	30.0
				1st Cl. Tails	3.43	0.46	7.7
				Rougher Tails	95.58	0.15	70.0
31	-37 µm (-400 mesh)	Xanthate 350	4	3rd Cl. Conc	0.14	17.06	11.4
				2nd Cl. Conc	0.20	13.50	12.9
				1st Cl. Conc	0.36	8.67	14.9
				Rougher Conc	7.19	0.98	33.5
				1st Cl. Tails	6.83	0.57	18.6
				Rougher Tails	92.81	0.15	66.5
33	-37 µm (-400 mesh)	CMC (3rd Cl. Fl.)	5	4th Cl. Conc	0.06	23.25	6.8
		Xanthate 350	8.5	3rd Cl. Conc	0.10	17.00	8.3
				2nd Cl. Conc	0.25	11.44	14.0
				1st Cl. Conc	0.56	6.46	17.7
				Rougher Conc	7.85	0.96	37.0
				1st Cl. Tails	7.29	0.54	19.3
				Rougher Tails	92.15	0.14	63.0
34	3-stage grinding -37 µm (400 mesh)	Xanthate 350	22.5	4th Cl. Conc	0.17	11.40	9.3
				1st Cl. Conc	1.56	2.67	20.0
				Rougher Conc	24.06	0.52	60.0
				1st Cl. Tails	22.50	0.37	40.0
				Rougher Tails	75.94	0.11	40.0

*g/t of ore

Based on the results of the flotation cleaning tests the following comments can be made:

(a) Upgrading the rougher concentrate to a relatively high grade nickel product was possible by successive cleaning stages. Concentrates of Ni content higher than 6% were obtained, for some tests, even in the 1st cleaner stage.

(b) The nickel recovery dropped significantly in the cleaning stages.

The first two flotation cleaning tests were carried out with ore ground to -74 microns. In test 29 an intensive rougher flotation was performed to boost the nickel recovery. A good amount of gangue minerals were entrained in the rougher concentrate but a large addition of CMC in the first cleaner stage (857 g/t of 1st cleaner feed) managed to remove most of the gangue in the 1st cleaner tails, for a nickel loss of 8.0%. The gangue was further controlled by successive additions of CMC without losing too much Ni in the subsequent cleaner tails. Thus the 2nd cleaner concentrate assayed 6.35% Ni for a nickel extraction of 30.5%.

In the next test (#30) where the weight of the rougher concentrate was kept low by reduced addition of frother, there was no need to control the gangue by CMC addition in the 1st cleaner stage. By strict froth control, again a substantial amount of gangue was dropped in the 1st cleaner tails for a nickel loss of 7.7%. The 2nd cleaner concentrate assayed 8.02% Ni but overall nickel recovery was only approximately 20%.

In the subsequent three tests with ore ground to -37 μm (400 mesh) elimination of the CMC addition and avoidance of the entrainment of the gangue minerals throughout the cleaning stages by a careful control of the froth was tried. However, in those tests this was not possible because of a much higher proportion of slimes produced by the finer grind. A substantial amount of material was again dropped in the 1st cleaner tails but the amount of nickel carried along was this time very high 18.6 - 40%.

Precious Metals Analysis of Flotation Concentrate

Two flotation cleaner concentrates were assayed for precious metals. The results are given in Table 8.

Table 8 - Precious metals assay

Test	Product	Ni	Au		Ag		Pt		Pd	
		%	oz/t	g/t	oz/t	g/t	oz/t	g/t	oz/t	g/t
31	3rd Cl. Conc	17.06	<0.001	<0.03	0.2	6.86				
30	4th Cl. Conc	12.30					0.012	0.41	0.006	0.21

The precious metals content in a nickel concentrate of 12-17% Ni was negligible.

MAGNETIC CONCENTRATION

The magnetic concentration of iron and chromium minerals was examined.

First, a series of Davis Tube determinations was carried out to evaluate the possibility of obtaining an iron concentrate, then magnetic separation tests were performed using several magnetic separators.

The conditions and results of these tests follow.

Davis Tube Determinations

Samples of original ore and flotation tailing at various grinding sizes were subjected to Davis Tube tests. The results are presented in Tables 9 and 10.

Table 9 - Davis Tube tests with original ore

Test no.	Grind % -74 µm	Cond. Amp.	Products	Weight		Assay %		% Dist.	
				g	%	Fe	Cr	Fe	Cr
0-1	95.4	1.8	Mags	6.0	9.6	40.2	1.72	57.6	60.4
			Non-Mags	56.6	90.4	3.14	0.12	42.4	39.6
			Head	62.6	100.0	6.7	0.27	100.0	100.0
0-2	100.0 and 98.0% -37 µm	1.8	Mags	3.5	6.8	56.4	2.02	53.8	49.5
			Non-Mags	47.7	93.2	3.54	0.15	46.2	50.5
			Head	51.2	100.0	7.1	0.28	100.0	100.0
0-3	100.0 and 98.6% -30 µm	1.8	Mags	2.1	4.5	50.9	1.90	35.8	32.2
			Non-Mags	44.3	95.5	4.30	0.19	64.2	67.8
			Head	46.4	100.0	6.4	0.27	100.0	100.0

Table 10 - Davis Tube tests with flotation tailing

Test no.	Grind % -74 µm	Cond. Amp.	Products	Weight		Assay %		% Dist.	
				g	%	Fe	Cr	Fe	Cr
4	95.4	1.8	Mags	5.2	11.1	37.5	1.52	60.0	61.2
			Non-Mags	41.8	88.9	3.12	0.12	40.0	38.8
			Head	47.0	100.0	6.94	0.28	100.0	100.0
16-A	100.0 and 98.0% -37 µm	1.8	Mags	3.5	7.8	53.90	1.90	56.7	51.7
			Non-Mags	41.4	92.2	3.48	0.15	43.3	48.3
			Head	44.9	100.0	7.41	0.29	100.0	100.0
28	100.0 and 98.6% -30 µm	1.8	Mags	3.0	6.2	59.3	2.00	55.4	50.4
			Non-Mags	45.2	93.8	3.16	0.13	44.6	49.6
			Head	48.2	100.0	6.64	0.25	100.0	100.0

The results of the Davis Tube determinations indicated that even at almost 100% -30 microns grind the separation of iron-chromium minerals was not possible, both following the same trend of concentration. Also, the iron content of the magnetic product could not be raised over 60%. The non-magnetic product remained high in Fe and Cr throughout the tests.

Magnetic Separation

A series of magnetic separation tests was carried out to confirm the Davis Tube results. All the tests but one were performed with flotation tailing resulting from rougher flotation, under -74, -37 and -30 microns grinding. One test was done with original ore ground to -74 microns.

Various magnetic apparatus were used: Sala permanent magnet, Sala High Gradient Magnetic Separator (HGMS), Jones and Jeffrey. The experiments carried out with Jeffrey were performed by Lakefield Research of Canada while the tests with the other equipment were done in our laboratory.

In tests 4-1 and 16A-1 the Ni flotation tailing was passed through Sala permanent magnet apparatus to separate the magnetite from chromite and other less magnetic minerals. Then the non-magnetic product resulting from this separation was processed in a Sala High Gradient Magnetic Separator at various intensities of the magnetic field to concentrate the chromite.

In tests 4-2, 16A-2 and 16A-3 the Ni flotation tailing was processed by Sala HGMS at the lowest intensity of the magnetic field (approximately 660 Gauss) under various flow rates. In one test, 16A-3, the magnetic concentrate obtained at 660 Gauss was repassed at a higher flow to improve its iron content, while the non-magnetic product was retreated at a higher intensity of the magnetic field (21.4 K Gauss) to separate the chromite.

In test 28-1 nickel flotation tailing of very fine grind (98.6% -30 microns) was passed through a Jones separator at zero amperage which corresponded to a residual magnetic field of 3000 Gauss. The purpose of the test was to concentrate the magnetite in the magnetic product.

Nickel flotation tailing at various grinds and original ore ground to 95.4% -74 microns was processed at Lakefield Research Laboratories in a Jeffrey separator for the purpose of producing a magnetite concentrate.

The results of the magnetic concentration tests are summarized in Table 11. Since the separation of iron and chromium minerals could not be

achieved the data presented in Table 11 referred to the magnetic product as resulting from the magnetic concentration process.

Table 11 - Magnetic concentration of flotation tailing and original ore

Flotation tailing

Equipment	Test no.	Grind	Mag. Field Gauss	% Weight	Assay %		% Dist.	
					Fe	Cr	Fe	Cr
Sala perm. magnet	4-1	-74 µm	600	5.7	39.9	1.44	32.9	30.3
	16A-1	-37 µm	600	3.4	25.8	0.95	12.1	11.4
Sala HGMS	4-2	-74 µm	660	19.0	15.8	0.70	55.6	49.1
	16A-2	-37 µm	660	14.8	13.9	0.60	41.0	32.2
	16A-3	-37 µm	660	40.6	10.7	0.47	70.0	73.8
Jones	28-1	-30 µm	3000	4.8	36.86	1.32	25.1	21.7
Jeffrey	23-1	-74 µm	320/1300	6.3	36.0	1.41	35.2	32.3
	17-1	-37 µm	600/1300	4.4	14.80	0.60	9.5	8.7
	28-1	-30 µm	800/1300	0.9	26.33	0.91	3.4	2.9
Original ore								
Jeffrey	-	-74 µm	320/1300	3.4	40.1	1.53	21.6	19.3

Based on the results of the magnetic concentration tests the following comments can be made:

(a) Separate concentration of iron and chromium minerals by magnetic separation was not possible even at a very low magnetic field (320 Gauss) or at extremely fine grinding (98.6% -30 microns). Both Fe and Cr followed the same trend of concentration throughout the tests.

(b) The grade of the magnetic concentrate for both Fe and Cr was far below the level of the saleable products. Contrary to what would have been expected and to what the Davis Tube tests showed the grade of the magnetic concentrate deteriorated with the fineness of grind. The highest Fe and Cr concentrate grade was obtained at 95.4% -74 microns (approximately 40% Fe and 1.5% Cr). Extremely intimate association between magnetite and other

minerals must have been the cause for the poor efficiency of the magnetic separation.

(c) The iron and chromium recovery for the best magnetic concentrates was quite low (below 35%). Sala HGMS gave higher Fe and Cr extraction but the grade of the magnetic product was too low to deserve further attention.

(d) No significant difference was found between the results of the magnetic concentration with flotation tailing or original ore (not subjected to flotation).

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn based on the results of the testwork with Border Resources ore:

(a) The ore exhibited a very low content in valuable metals making the task of upgrading the material to saleable products difficult to achieve.

(b) Extremely intimate association of the minerals among themselves reduced very much the efficiency of concentration for all methods tried in this testwork.

(c) Nickel and cobalt can be recovered by flotation and concentrates of 6% Ni or more were obtained but the nickel extraction, at this level of concentration, did not exceed 30%. Continuous operation with middlings recirculation will probably be able to increase somewhat the nickel recovery but it is unlikely that under the most optimistic conditions a recovery in excess of 50% will be obtained.

(d) Precious metals (Au, Ag, Pt, Pd) concentration in flotation products of high Ni grade was insignificant and therefore little economic benefit should be expected from this part.

(e) Separate concentrates of iron and chromium could not be obtained by magnetic separation. Even at an extreme fine grind and under very low intensity of magnetic field the two constituents remained unseparated, showing at all times similar distribution in the magnetic and non-magnetic products.

(f) The grade of the Fe-Cr product obtained by magnetic concentration was far below that of a saleable concentrate and the recovery in both metals remained very low under all tested conditions. It is unlikely that by mineral dressing methods an efficient separation of Fe-Cr minerals can be obtained.

Although the results of this testwork were not quite satisfactory it must be recognized that some progress in the recovery of nickel minerals was definitely achieved. It was proved that a good part of the nickel minerals showed a positive response to flotation; concentrate of over 20% Ni being produced under strictly controlled conditions. These results deserve further attention and constitute a good ground to continue the investigation for the beneficiation of this ore.

The following recommendations are offered:

1. Develop a scientifically oriented prospecting program to locate zones in the ore body of better mineralization. Apparently there are some scientific grounds to support the idea that such zones of higher nickel concentration does exist in that geological formation.

2. Continue the mineralogical investigation to identify the intimate structure and nature of the mineralization. Ni-Co as well as Fe-Cr minerals should be the main object of this research work.

3. Submit samples of original ore to various manufacturers of magnetic separation equipment to obtain more information about the possibility of concentrating the iron and chromium minerals by this method.

4. When better nickel mineralization is found resume the flotation testing program for the recovery of the nickel, cobalt and other possible constituents including precious metals.